



On the Elimination of Nitrogen by the Kidneys and Intestines
during Rest and Exercise, on a Diet without Nitrogen. By
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The experiments recorded in this paper were undertaken to test the results arrived at by Professors Fick and Wislicenus, with respect to the elimination of nitrogen during exercise on a non-nitrogenous diet, as recorded in the Philosophical Magazine for June 1866 (Supplement).

Although these results are supported by the previous experiments of Dr. Speck, who has shown that if the ingress of nitrogen be restricted, bodily exercise causes no, or a very slight increase in the elimination of nitrogen by the urine, it appeared desirable to carefully repeat all the experiments, not only because the question is one of great importance, but because objections might be, and indeed have been, reasonably made to the experiments of Professors Fick and Wislicenus on the ground that no sufficient basis of comparison between periods of rest and exercise was given; that the periods were altogether too short, and that no attention was paid to the possible exit of nitrogen by the intestines.

In making the experiments, I was fortunate in being permitted to use the services of two perfectly healthy soldiers belonging to the Army Hospital Corps, and doing duty at the Royal Victoria Hospital at Netley. When soldiers are steady and trustworthy, as these men were, they are good subjects for experiments of the kind, as they are accustomed to very regular diet and occupation, and moreover, from their habits of obedience, carry out all instructions with great precision. The satisfactory results of my experiments, as shown by the almost perfect agreement in the effect on each man, is owing essentially to the very great care with which these two intelligent men carried out every rule which was laid down.

One of these men, S., is an admirable example of an average man; he is $22\frac{1}{2}$ years old, 5 feet 8 inches in height, weighs close upon 150 lb., is strong, with large bones and firm muscles, with sufficient but not excessive fat; he is very temperate, and is no smoker. He has never been ill in his life. The second man, T., is also a perfectly healthy man, and has only been ill twice, once in China six years ago with tertian ague, and about three years ago with intermittent hemicrania. But he is in size and weight a good contrast to S. He is 36 years of age, very well proportioned and active, but is only 5 feet 4 inches in height, and weighs only

112 lbs. His size is not owing to any imperfection in make or nutrition, but to the fact that he comes of a small race, his father being small, and his mother remarkably so. He has small bones, good firm muscles, but very little fat. In fact, he is a thin man.

In the following experiments, the amounts of the total nitrogen of the urine (by soda-lime), of the urea, of the chloride of sodium, and on certain occasions of the phosphoric and sulphuric acids, were determined. The urea was determined by Liebig's solution, the chlorine being first eliminated, the phosphoric acid by acetate of uranium, the sulphuric acid by baryta and weighing.

The urine was collected from 8 A.M. to 8 A.M., and great care was taken not to lose any, and to pass it at the exact time.

The amount of water, solids, and nitrogen passed from the bowels were also determined on several occasions.

All the ingesta were most carefully weighed and measured, and the amount of water in the crumb and crust of bread and in the meat was determined. The nitrogen in the bread was also determined, but the long time demanded by the other processes prevented a complete analysis of the other food; this was, however, a matter of no importance as regarded the immediate object of the inquiry.

The experiments were commenced on December 6, 1866, and were continued daily till December 23.

First Period of ordinary regulated Diet and Occupation.

The men were first kept under observation for six days, in order to determine the variations in weight and in the excreta, and to see if the metamorphosis of tissue appeared to be healthy. This was found to be the case; in fact, more completely healthy urinary and intestinal excreta could not be conceived.

The weight of the body ranged nearly 1 lb. avoird., or $\frac{1}{2}$ kilog. above and below the mean amount in each man.

The daily average amount of food and drink was only slightly different in each man, and the quantity taken from day to day was very uniform.

The men were not placed on any absolute quantity, but ate according to appetite within narrow limits.

Average daily amount of food in ounces avoirdupois in this period:—

	S.	T.
Cooked meat	7.625	7.625
Bread	16.66	16.26
Vegetables:— $\frac{3}{4}$ potatoes, $\frac{1}{4}$ cabbage	13.87	13
Butter	1	1
Tea, including 3 oz. of milk, and $1\frac{1}{2}$ oz. sugar	20	20
Coffee, including 3 oz. of milk, and $1\frac{1}{2}$ oz. sugar	20	20
Beer	15	15
Water	5.8	2.33

S. took about .5 oz. salt and T. about .33, exclusive of salt in food. Adding the water of the so-called solid food to the water taken as drink, the daily amount of food was, in grms.—

	S.	T.
Water-free solids, in grms.	662.2	610.2
Water, in grms.....	2334.5	2212.3
Total food ingesta	2996.7	2822.5

The mean weight of this period was for S. 67.7 kilogs. and for T. 50.6 kilogs. The ingress of solid food per kilog. of body-weight was 9.78 and 12 grms. respectively. The smaller man eat therefore absolutely rather less, but relatively more.

During four days of this period the mean daily urinary excretion was, in grms. and cubic centimetres—

	Quantity.	Sp. gr.	Urea.	Nitrogen in urea.	Total nitrogen by soda-lime.	Non-ureal nitrogen.	Chloride of sodium
S.	1226	1028.25	35.001	16.334	17.973	1.639	14.23
T.	1335	1020.5	25.925	12.098	13.409	1.313	11.685

The excretion of nitrogen was fairly constant from day to day, the range of the urea being, in the case of S., from 38.37 to 33.36 grms., or between 2 and 3 grms., above and below the mean amount; and in the case of T. from 27.68 to 24.906, or nearly 1 grm. above and below the mean amount. This shows the daily equality of diet and exercise.

Calculated for body-weight, the amount per kilog. is—

	Urea.	Nitrogen in urea.	Total nitrogen.	Non-ureal nitrogen.
S. ....	.517	.241	.265	.024
T. ....	.512	.239	.265	.026

The very close relation, indeed identity, as far as the total nitrogen is concerned, of the excretion per kilog. of body-weight in these two men comes out very clearly, and shows that there must be a real connexion between body-weight and urinary excretion.

It is remarkable that while the heavier man passed 4½ grms. more nitrogen daily from the kidneys than the smaller man, he did not eat any great excess of food. Unfortunately, as the nitrogen in the food was not perfectly determined, it is impossible to know precisely whether the 52 grms. of excess of solid food taken by the larger man would contain 4½ grms. more nitrogen. As, however, the amount of meat was precisely the

same, and as the smaller man only took $\frac{1}{2}$ oz. or 14 grms. less bread, and 25 grms. less vegetables, this would seem to be unlikely, and, if so, some of the nitrogen taken by T. must have passed off in other ways.

The mean relation of the ureal to the total nitrogen was very close in each man, being, if the ureal nitrogen is taken as unity, as 1 to 1.1, and as 1 to 1.108 respectively. From day to day, however, the relation varied.

The intestinal excretion was examined only on one day, the last but one of the series.

Composition of Intestinal Excretion of Twenty-four Hours.

	Total weight, in grammes.	Solids.	Water.	Nitrogen in grammes.
S.	171.1	28.58	142.52	1.642
T.	198.47	29.916	168.55	1.98

The smaller man passed rather more solids, water, and more nitrogen than the larger man, and through this channel some of the nitrogen unaccounted for by the urine must have escaped. Whether this would account for the whole of it cannot be stated, as the experiments in respect of the nitrogen in the food and in the intestinal excreta of the whole period were not sufficiently exact to determine this point.

On the day when the intestinal excreta were analyzed, the total discharge of nitrogen by the kidneys and bowels was—

	S.	T.
Urine.....	20.155	13.410
Bowels	1.642	1.980
Total....	21.797	15.390

In S. nearly $\frac{1}{13}$ th, and in T. nearly $\frac{1}{8}$ th of the total nitrogen passed by the bowels.

On the day when the intestinal excreta were analyzed, the balance of ingesta and egesta, atmospheric oxygen being disregarded, was as follows:—

	S.	T.
Weight of body at commencement of } period, in kilogrammes	67.6	50.76
Weight of body at close	68.	50.89
Gain or loss, in grammes.....	+ 400	+ 130
Total ingesta by food and drink, in } grammes	3083	2969
Urinary egesta ,, 	1619	1774.8
Intestinal egesta ,, 	171.1	198.47
Skin and lung egesta ,, 	893	866

The tissue-changes in these two men are therefore very closely the same, and the men are quite comparable and well fitted for the experiments. T. has rather a larger excretion (chiefly of water) by the kidneys

and bowels, and rather less by the skin, but the difference is not great. He has also a larger excretion of nitrogen by the *bowels* than S.

Second Period.—Non-nitrogenous Diet and Rest.

On the day following the men were placed for two days on a non-nitrogenous diet consisting of arrowroot, sugar, and butter, from which the casein had been separated. The only nitrogenous substance taken was that contained in infusion of tea. I thought it better to allow the use of warm tea, without milk, both for the comfort of the men and because I was afraid of deranging the tissue-changes by too complete an alteration of diet.

The arrowroot was made into cakes with butter and sugar, and was also taken as jelly. Butter and sugar were taken as desired. I put no restriction on quantity, but left it to choice and appetite.

The following was the total diet of two days, December 10th to 11th, and 11th to 12th, in grammes :—

	S.	T.
Water-free arrowroot	480	382·7
Water-free sugar	399·7	294·8
Total dry carbohydrates	879·7	677·5
Butter (without casein)	124·7	84·4
Total water-free food in two days..	1004·4	761·9

Proportion of fat to carbohydrates 1 to 7, 1 to 8.

The dry starches and butter being assumed to be of their ordinary composition, the *daily* amount of carbon would be, in grammes,—

	S.	T.
In arrowroot and sugar.....	195·33	150·4
In butter	49·25	32·83
Total	244·58	183·23

	grms.	grms.
The amount of water taken in the two days..	4592	4592

It is of no consequence to calculate the proportion to body-weight, as some starch and sugar passed off by the bowels.

During these two days the men were kept in complete rest. They were allowed to get up for fear keeping in bed should make them feverish, but they sat quite still, or lay down on the bed, and did not leave the room during the time.

The *weight* decreased in the case of S. from 67·7 to 66·5 kilogrammes, and in the case of T. from 50·6 to 49·8 kilogrammes.

The *Urinary Excretion* was collected as usual on the first day, from 8 A.M. to 8 A.M.; but on the second day it was collected from 8 A.M. to 8 P.M., and again from 8 P.M. to 8 A.M., so that the last twelve hours' urine was secreted forty-eight to sixty hours after the last meal of nitrogenous food.

The full details are given further on, and I will now merely state the mean results.

On the mean of the two days the urea of twenty-four hours fell from 35 grammes to 16·765, or more than one-half in the case of S., and from 26 to 15, or rather less than one-half in the case of T.

The amount of urea in the last twelve hours was only 5 and 4·2 grammes for the two men. The total nitrogen, or a mean of the two days, fell from 17·97 and 13·4 to 8·176 and 7 grammes in the two men, while in the last twelve hours it was only 3·017 and 2·17 grammes, or at the rate of only 6·034 and 4·34 grammes in twenty-four hours.

Calculated according to body-weight, the results are per kilogramme :—

	Urea.	Nitrogen in urea.	Total nitrogen.	Non-ureal. nitrogen.
S.	·252	·118	·136	·018
T.	·301	·141	·159	·018

A more satisfactory comparison may perhaps be made by taking the last day only as representing more complete nitrogenous inanition.

Per kilogramme of body-weight.

	Urea.	Nitrogen in urea.	Total nitrogen.	Non-ureal nitrogen.
S. ...	·2034	·0949	·1054	·0105
T.	·2540	·1180	·1420	·0130

Therefore during complete nitrogenous inanition the tissues of the smaller and older man furnished a slightly greater amount of nitrogen than those of the larger man, and this is evident both in the ureal and non-ureal nitrogen, so that it could scarcely be accidental.

The sulphuric acid and phosphoric acids were determined on the last day; the latter acid was in almost precisely the same absolute mean amount in each man, viz. ·9533 and ·941 gramme; the larger man passed, however, one-third more sulphuric acid, viz. ·633 as against ·427 gramme.

In the last twelve hours the chloride of sodium fell to 1 and ·42 gramme.

The Intestinal Excretion.

This was examined on the last day. The composition was—

	Total weight, in grammes.	Solids.	Water.	Nitrogen.
S.	42·53	6·6	35·93	·3875
T.	35·44	6·55	28·89	·5360

The amount of solids was almost identical, but S. passed less nitrogen than T., as occurred also in the first period. The excreta were quite bilious, and had a greenish tint.

On the second day of nitrogenous inanition the balance of ingesta and egesta was as follows:—

	S.	T.
Weight of body at commencement of period,		
in kilogrammes	66·89	50·1
Weight of body at close of period	66·19	49·6
Gain or loss, in grammes	—680	—500
Total ingesta in food and drink, in grammes	2995	2907
Urinary egesta „ ..	2477·5	2306
Intestinal egesta „ ..	45·53	35·44
Skin and lung egesta „ ..	1155	1065·5

The considerable derangement of the usual balance is very evident; it depended in part on the greater amount of water taken as compared with the former period, but not apparently altogether.

The water of the kidneys and the insensible perspiration were increased, while the intestinal water was lessened.

There was no sugar in the urine detectable by common tests.

The effects of the diet in the two men being thus very similar, a satisfactory basis of comparison was obtained for the period of exercise.

Third Period.—Ordinary Food and Occupation.

The men then returned to their former regulated diet and usual occupation for four days. Very nearly the same amount of food was taken as in the first period. At the end of four days the weight of the body in each man had returned almost exactly to its former amount.

The excretion of urea and the total nitrogen (which is given in more detail further on) followed a course very similar in each man.

On the first day after the return to nitrogenous diet the urea was in round numbers 14 and 12 grammes respectively below the mean of the first period, that is to say, it was nearly the same as during the first day of non-nitrogenous feeding; it then, in the case of S., increased day by day till it reached 29·67 grammes on the fourth day. In the case of T. it increased for two days, but fell a little on the fourth day; the total nitrogen, however, increased regularly every day.

The general result was that whereas in four days of the first period on a similar diet and exercise the excretion of nitrogen was 71·892 and 53·636 grammes respectively, during these four days of the third period the excretion of nitrogen in the urine was only 51·952 and 44·38 grammes; so that in the case of S. 19·94 and in the case of T. 9·256 grammes of nitrogen were retained in the body for the nutrition of the nitrogenous

tissues which had been brought into a state of nitrogenous inanition for two days by cutting off the supply of nitrogen.

At the end of the four days it was considered that the tissues had recovered their composition.

Fourth Period.—Non-nitrogenous Diet and Exercise.

Diet.—The diet during this period was of the same kind as in the second period. The men were directed to eat what they pleased of arrowroot made into cakes, and jelly, sugar, and the oil of butter.

They took in the two days of December 17–18, and 18–19, the following amounts :—

Non-nitrogenous Food in two days, in grammes.

	S.	T.
Water-free arrowroot	796·6	586·8
Water-free sugar	421·5	360·0
Total dry starches	1218·1	946·8
Butter (without casein)	188·5	127·5
Total water-free food.....	1306·6	1074·3
Proportion of fat to starches	1 to 6·46	1 to 7·42

The daily proportion of carbon was—

	S.	T.
In starches	270·400	210·189
In butter	74·478	50·395
Total	344·878	260·584

The amount of water drank in the two days was. . 5159·5 4762·6.

Both men eat more during this period, partly because they felt more hungry, partly because the arrowroot-cakes were better made. T. especially took more butter, to which he felt a distaste previously.

The diet satisfied hunger ; there was no sinking or craving for other kind of food, but it was monotonous, and neither man wished to continue it.

Exercise.—During these two days the men took the following amount of walking-exercise, on level ground. On the first day the exercise commenced at 9 A.M., and lasted till 7.45 P.M. with intervals. On the second day it commenced at 9 A.M., and lasted till 9 P.M. The men then went to bed.

First day.—23·76 miles=38·23 kilometres.

The work done was calculated according to Professor Haughton's for-

mula, that walking on a level surface is equal to lifting $\frac{1}{20}$ th of the weight through the distance walked.

S., weight with clothes, 73·68 kilogrammes. Work done = 140839 kilogramme-metres, or 453·6 tons lifted a foot.

T., weight with clothes, 56·33 kilogrammes. Work done = 107655 kilogramme-metres, or 346·74 tons lifted a foot.

Second day.—Distance walked 32·78 miles = 52·74 kilometres.

Work done.

S. = 194294 kilogramme-metres.

= 625·8 tons lifted a foot.

T. = 147515 kilogramme-metres.

= 475 tons lifted a foot.

The first day's walking was done pretty well by both men. On the second day both men did the first 20 miles well, but felt very much fatigued during the last 13 miles. During the last 4 miles each man felt pain in the small of his back. Both men could, however, have marched on the following day if necessary.

With regard to the amount of fatigue as compared with other occasions, T. would give no opinion, as he said he had no fair basis of comparison. S., however, was clear that he was much more fatigued than on other food. In 1865 in Ireland he marched 26 miles on one day and 20 on the following, carrying his rifle, accoutrements, and forty rounds of ball-cartridge (an additional weight equal to 18 lb. nearly), and yet he did not feel fatigued at all; while on the present occasion, marching without weight except his clothes, he felt much exhausted.

Both men felt hungry; the food satisfied them; neither had any perceptible action of the skin; the days were fine and rather warm. During these two days S. lost almost precisely 2 kilogrammes in weight, and T. lost $\frac{3}{4}$ of a kilogramme.

The Urinary Excretion.—The urine was collected as usual from 8 A.M. to 8 A.M. on the first day, and from 8 A.M. to 8 P.M., and from 8 P.M. to 8 A.M. on the second day. In order to compare this, I have placed together the chief urinary constituents in the two periods of rest and exercise.

Amount of Urine, in cubic centimetres.

	S.		T.	
	Rest.	Exercise.	Rest.	Exercise.
First 24 hours	2230	2550	2120	1650
First 12 hours of second day } (day urine)	1550	1210	1690	1000
Second 12 hours of second } day (night urine)	910	1020	600	650

Excretion of Nitrogen, in grammes, in Urine.

	S.				T.			
	Urca.		Total nitrogen by soda-lime.		Urca.		Total nitrogen by soda-lime.	
	Rest.	Exer- cise.	Rest.	Exer- cise.	Rest.	Exer- cise.	Rest.	Exer- cise.
December 17-18, first 24 hours	20·00	19·125	9·33	10·048	17·3	16·005	8·765	7·994
December 18, first 12 (day) hours of second day	8·525	7·865	4·005	4·533	8·45	8·000	4·912	4·522
December 18-19, last 12 (night) hours of second day	5·005	7·140	3·017	3·360	4·2	5·200	2·170	3·553
Total in two days...	33·530	34·130	16·352	17·942	30·030	29·205	15·847	16·069

The excretion of the urea was very parallel in the two men, and followed this course. In each man in the first twenty-four hours nearly 1 gramme less was excreted by each man in the period of exercise as compared with that of rest; the larger man excreted nearly 3 grammes more urea than the smaller one.

In the next twelve hours each man excreted very nearly $\frac{1}{2}$ a gramme less in the period of exercise as compared with rest. The absolute quantity was almost precisely the same in each man; in other words, the bulk of the larger man now had no effect in the urea.

In the last twelve hours (chiefly rest during night) the urea increased in each man in the period of exercise, as compared with that of rest, the absolute increase in S. being 2 grammes, and in T. 1 gramme.

Taking the whole period,—

Excretion of urea in two days in the period	S.	T.
of exercise as compared with rest.....	+0·60	—·825

The results, when the total nitrogen is considered, are as follows:—

Slightly more nitrogen was excreted by S. in the period of exercise throughout; the excess being,—

	gram.
In the first 24 hours	0·718
In the next 12 hours.....	0·528
In the last 12 hours	·343

Total excess of nitrogen during exercise period . 1·589

In the case of T. the total nitrogen during exercise was like the urea below the period of rest in the first 36 hours, but in the last 12 hours the excess of nitrogen in the period of exercise was so considerable as to cause the nitrogen of the two days of exercise to exceed that of rest by 0·223 gramme.

I draw the conclusion, therefore, that in both these men there was in the first 36 hours a decrease in the amount of urea ; but in the last 12 or rest-hours of the 48 hours of the period of exercise, an increase.

That in the case of S. the total nitrogen was increased throughout the whole period of exercise, the total increase being 1·589 gramme, or 24·5 grains of nitrogen, while in the case of T. the total nitrogen, like the urea, was lower in the first 36 hours of the period of exercise, but increased greatly in the last 12 hours.

It may, indeed, be said that the difference between the amounts in the two periods is after all so inconsiderable as to be explained by the necessary errors of observation. But the constancy of the results in the two men, and in the case of T., the amount on the first day after the work-period, as given further on, seem to me to show the excess to be real.

On the same diet the heavier man excreted rather more urea and total nitrogen throughout than the smaller man, except in the first 12 hours of the second active day, when the urea was a trifle less.

The excretion of nitrogen in the urea, as compared with the total nitrogen, was (the ureal nitrogen being taken as unity) as follows :—

	S.	T.
Period of rest	1 to 1·042	1 to 1·13
Period of exercise	1 to 1·126	1 to 1·178

In both cases there appears to have been a greater relative excretion of the nitrogenous substances other than ureal. Is it not probable that the creatinine was increased ?

The Phosphoric Acid.

	S.		T.	
	Rest.	Exercise.	Rest.	Exercise.
First period of 24 hours . . . . .	.....	1·873	.....	1·144
First 12 hours of second period ..	·4930	·395	·5102	·5305
Second 12 hours of second period	·4603	·749	·4308	·3978
Total in last 24 hours	·9533	1·144	·9410	·9283

On a non-nitrogenous diet the amount of phosphoric acid is not increased in a period of exercise as compared with a like period of rest. The immaterial increase in S. is counterbalanced by as slight a decrease in T.

The Sulphuric Acid.

	S.		T.	
	Rest.	Exercise.	Rest.	Exercise.
First 12 hours of second day (day) . .	·372	·3791	·232	·1544
Second 12 hours of second day (night)	·261	·3084	·195	·3011
Total on second day	·633	·6875	·427	·4555

The sulphuric acid was slightly increased in each man, but the increase was not great, and is perhaps within the limits of error.

Chloride of Sodium.

As no chloride of sodium was taken with the non-nitrogenous diet, the amounts excreted represent on the second day the mere waste of the tissues.

	S.		T.	
	Rest.	Exercise.	Rest.	Exercise.
First 24 hours	6.914	3.280	4.9	1.866
First 12 hours of second day (day time)	2.81	.673	1.88	1.094
Last 12 hours of second day (night time).	1.01	.119	.42	.150
Total of last day	3.82	0.892	2.30	1.244

As the results agree in both men, it appears that on a diet free from common salt much more chloride of sodium passes with the urine during rest than exercise ; it is to be inferred that in the latter case chloride of sodium passes off by the skin.

No sugar was detected in the urine by the ordinary tests of liquor potassæ and Fehling’s copper solution.

Intestinal Excretion.

This was examined on the last day, and was as follows :—

	Total weight, in grammes.	Solids.	Water.	Nitrogen.
S. ..	100.5	5.63	94.87	.5318
T. ..	120.7	11.012	119.688	.5739

If these numbers are compared with those of the corresponding period of rest, it appears that the total intestinal excretion was larger, but this arose in one man from an excess of water ; in the other the solids were increased. In both men the nitrogen was in excess in the period of exercise, but the difference was not great, and may probably be disregarded.

Balance of Ingesta and Egesta.

On the second day of the non-nitrogenous diet and exercise, the balance of ingesta and egesta was as follows :—

	S.	T.
Weight of body at commencement of period, in kilogrammes .	66.66	50.1
Weight of body at close of period	65.73	49.87
Gain or loss, in grammes	—930	—230
Total ingesta in food and drink, in grammes	3639	3124
Urinary egesta	2247	1667
Intestinal egesta	100.5	120.7
Skin and lung egesta	2221.5	1556.3

If these numbers are compared with those given in the corresponding

period of rest, it will be seen that in both men the skin and lung egesta were very greatly increased (nearly 100 and 50 per cent. respectively); the intestinal egesta were also much larger; the urinary smaller, especially in the case of T., who passed nearly 800 cub. centims. less of urine, though he took more fluid as drink.

Neither of the men were conscious of any perspiration.

Fifth Period.—Ordinary Diet and Exercise.

The men were now again placed on their weighed diet, and took their ordinary exercise for four days, except that on the day following the walk of 33 miles they were tired and rested a good deal.

This period has now to be compared with the third period, which followed that of rest. As the amount of diet is very important, I give the mean amount in each of the four days of the third and fifth period, in English ounces.

Daily amount, in ounces (437·5 grains).	S.		T.	
	Thirđ, or after rest-period.	Fifth, or after work-period.	Thirđ, or after rest-period.	Fifth, or after work-period.
Cooked meat.....	8·5	9·81	6·625	7·87
Bread.....	17	16·18	16·25	16·75
Vegetables— $\frac{3}{4}$ potatoes, $\frac{1}{4}$ cabbage.....	13·68	14·62	13·5	14·37
Butter	1	1	1	1
Tea, with 1½ oz. of milk, 1½ oz. of sugar	20	20	20	20
Coffee, with same amount of sugar and milk ..	20	20	20	20
Ale.....	21	20	18	20
Salt uncertain				

In the fifth period each man took rather more than an ounce more meat; S. took $\frac{8}{10}$ oz. less bread, and T. $\frac{1}{2}$ an ounce more; each man took $\frac{3}{4}$ of an ounce more vegetables, and 1 and 2 ounces more water. It is to be regretted that the diet was not precisely the same; but the differences are not very great, and it was thought desirable to allow the men to satisfy their appetites. They were more hungry after the work-period than after the rest-period.

The *weight* increased in this period. In two days S. gained 1½ kilogramme and T. 1¼ kilogramme, each man nearly getting his proper weight.

The Urinary Excretion.

The quantity of Urine.

	S.		T.	
	After rest-period.	After work-period.	After rest-period.	After work-period.
Mean of 4 days.....	1139	1028	1500	1495

There was scarcely any difference in T., and only 10 per cent. difference in S.

The Nitrogen.

	S.				T.			
	After rest-period.		After work-period.		After rest-period.		After work-period.	
	Urea.	Total nitrogen by soda-lime.	Urea.	Total nitrogen by soda-lime.	Urea.	Total nitrogen by soda-lime.	Urea.	Total nitrogen by soda-lime.
First day	20·67	9·703	20·8	10·237	14·40	7·441	23·00	11·58
Second day	25·68	12·304	26·364	13·065	23·00	11·480	24·36	13·00
Third day	26·29	13·704	28·32	14·590	25·20	12·209	24·57	
Fourth day	29·67	14·260	30·10	15·555	22·99	13·231	21·36	10·395
Mean	25·555	12·988	26·396	13·361	21·397	11·095	23·322	11·658
								Mean of 3 days.

Unfortunately, on the third day, in the case of T., the determination of the nitrogen by soda-lime was not satisfactory, and as some time elapsed before it could be again done, the amount has been omitted. But supposing there was the same relative excess over the ureal nitrogen as in the other days, the total nitrogen would have been 13·97 grms. Adopting this number, the following are the results :—

	S.	T.
Excess of urea in four days in after work-period.....	3·364	7·700
Excess of total nitrogen in four days in after work-period.....	1·492	4·560

The question now arises, was this excess of nitrogen excreted during the after work-period the result of the elimination of the products of destroyed muscle during the work-period, or was it the consequence of an excess of nitrogenous food in the four days following the exercise ?

S. took 1·31 oz. avoirdupois more meat cooked and $\frac{3}{4}$ oz. vegetables in the fifth than in the third period. The percentage of water in the meat was 57·49, and if the nitrogen be taken at 2·955 per cent., there would be in 1·31 oz. of cooked meat 1·1 gm. of nitrogen. In the vegetable there would be about 0·04 gm. of nitrogen. But from this amount must be deducted ·325 gm. of nitrogen not taken in the bread, making the total daily excess of nitrogen taken in the fifth period ·815 gm.; the daily excess of nitrogen in the urine was, however, only ·375 gm. ; therefore, in the case of S., it cannot be affirmed that any excess of nitrogen was derived from disintegration of muscle during the exercise. In the case of T., the daily excess of nitrogen was larger, amounting daily to

1·14 grm., but as the man took 1·245 oz. more meat, $\frac{1}{2}$ oz. more bread, and almost an ounce more vegetable (in all 1·2 grm. of nitrogen), it is evident that here also the excess of nitrogen in the urine might have been derived from the food. However, it is really probable that some of the very large excess of urea on the first day of this period, in the case of T., was really owing to augmented elimination from the work. No such excess is observable in the case of S., who had, however, a larger elimination than T. in the previous twelve hours.

The Chloride of Sodium.

The chloride of sodium rapidly returned to its previous amount.

	S.	T.
First day	1·444	1·614
Second day	6·169	4·905
Third day	10·25	8·513
Fourth day	8·117	6·446

It will be remembered that T. always took less salt than S. The third period is not comparable with the fifth, as the men took by mistake a great deal of salt on the second day.

The Phosphoric Acid.

	S.	T.
First day	1·565	2·158
Second day	2·413	2·273
Third day	2·548	2·533
Fourth day	2·408	2·065

As the phosphoric acid was not determined in the third period, no comparison is possible, but the above Table shows that no excess passed off in the after-period.

The sulphuric acid was not determined in this period.

The Intestinal Excreta, in grammes.

	S.				T.			
	Total weight.	Solids.	Water.	Nitro-gen.	Total weight.	Solids.	Water.	Nitro-gen.
Dec. 19-20; first day ...	298	.....	.....	.....	127·5			
Dec. 20-21; second day.	191·7	.....	.....	.....	213			
Dec. 21-22; third day...	134·9	21·86	113·02	1·264	71	11·8	59·2	·7188
Dec. 22-23; fourth day.	171·1	.....	.....	.....	191·7			

The large intestinal excretion on the first day, in the case of S., was owing to a little looseness of the bowels; there were two stools on that day, being the only instance of irregularity in either man. Otherwise, as

compared with the first period, there is no evidence in either case of any increased excretion ; on the third day, indeed, the nitrogen was below that of the first period in each case.

The balance of ingesta and egesta was as follows on the third day of this period :—

	S.	T.
Weight of body at commencement...	67·1	50·07
Weight of body at close	67·08	50·08
Gain or loss, in grammes	—20	+10
Food and drink ingesta	2891·7	2877·5
Urinary egesta	1808·7	1922·5
Intestinal egesta	134·9	71
Skin and lungs egesta	968·1	894

These numbers are fairly accordant with those of the first period, except that the intestinal excretion in T. was slightly less, and the urinary rather more.

The conclusions which can be drawn from the above experiments are not altogether accordant with those of Professors Fick and Wislicenus.

The decrease in the urea during the first thirty-six hours of the exercise-period, as compared with the rest-period, on a diet without nitrogen, which occurred in these two men, is, I think, conformable with the results obtained by the two experimenters mentioned ; but this is not the case with the increase in the urea which I found in the last twelve hours. Yet that this increase is real is shown, I believe, by the accordant results in the two men, and by the increase of the total nitrogen of the exercise-period as determined by soda-lime.

The relative greater increase in my experiments of the non-ureal nitrogen (which makes me believe that an excess of nitrogenous compound other than urea, and possibly creatinine especially, was produced by the exercise) is not perceptible in their experiments, yet I cannot but believe that the fact was so, as it comes out with great clearness in the two men. The following Table shows this.

Relation of ureal to non-ureal nitrogen, the former being taken as unity.

	S.	T.
Before rest-period	1 to 1·1	1 to 1·108
Rest-period	1 to 1·042	1 to 1·13
After rest-period	1 to 1·009	1 to 1·116
Work-period	1 to 1·126	1 to 1·178
After work-period	1 to 1·08	1 to 1·06 (?)
		(three days).

The reason which makes me believe the results are real, is the fact that the individual relation of the ureal and non-ureal nitrogen is preserved ; that is to say, in T. the non-ureal nitrogen is, under normal circumstances, a little in excess as compared with S. ; the same relative excess is also found in the work-period.

The reason of these differences between Professors Fick and Wislicenus and myself, is probably to be found in the short period of time during which their observations were carried on, and also because the urea was not determined by them in the night of the 30th to 31st of August.

But their conclusion is certainly borne out, that on a non-nitrogenous diet exercise produces no notable increase in the nitrogen of the urine, although, when the whole period is considered, it does produce a slight increase.

It may now also be said that, under similar conditions, exercise produces no increase in the excretion of nitrogen by the bowels.

The diminution in the amount of urea during the actual period of work, as compared with the rest-period, which, if I am not mistaken, is obvious in both our experiments, is a very curious circumstance. It shows, not that on a non-nitrogenous diet the nerves and muscles are totally unaffected by exercise, but that changes go on which either retain nitrogen in the body or eliminate it by another channel.

Is it possible that when the excess of nitrogen is restricted, the exhausted muscle will take nitrogen from the products given off from another portion of decomposing muscle, and thus the nitrogen may be used over and over again? or, after all, is nitrogen really given off in some form by the skin during exercise, as formerly supposed?

Although it is thus certain that very severe exercise can be performed on non-nitrogenous diet for a short time, it does not follow that nitrogen is unnecessary. The largest experience shows not only that nitrogen must be supplied if work is to be done, but that the amount must augment with the work. But for a short period the well-fed body possesses sufficient nitrogen to permit muscular exertion to go on for some time without fresh supply. But the destruction of nitrogenous tissues in these two men is shown by the way in which, when nitrogen was again supplied, a large amount was retained in the body to compensate for the previous deprivation.

I believe also that in these two men the great exhaustion of the second day showed that their muscles and nerves were becoming structurally impaired, and that if the experiments had been continued there would have been on the third day a large diminution in the amount of work.

I have found that the period when a restricted supply of nitrogen begins to tell on the work differs in different men; in one experiment I reduced the nitrogen in the food to one half its normal quantity in two men; in one no effect was produced on exercise in seven days, in the other a lessening of active bodily work was produced in five days; doubtless the previous nutrition of the muscle would influence the time.

Finally, it may be questioned whether the relation of elimination of nitrogen to exercise can be properly determined in this manner, *i. e.* by cutting off the supply of nitrogen. The true method would probably be to supply nitrogen in certain definite amount, so that the acting muscle might appropriate at once what it required.

